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LABORATORY MEASUREMENTS OF SEISMIC Q FOR EVALUATION OF PROPOSED ATTENUATION MECHANISMS, B. R. Tittmann, V. A. Clark, L. Ahlberg, Rockwell International Science Center, Thousand Oaks, California, and T. W. Spencer, Texas A & M University, College Station, Texas.

The presence of water is well known to affect many mechanical properties of rocks and its absence on the moon is thought by many to give rise to the extraordinary high Q values deduced from the seismic data. Many mechanisms such as breaking of cold welds, water assisted crack growth, stress induced diffusion of H₂O films, boundary lubrication, or dislocation motion have been suggested to account for the ability of small amounts of water to reduce Q. To test and guide theoretical models we have undertaken a series of experiments to document Q values in rocks under various conditions and as a function of several parameters.

Is water unique in its effects on Q, how does it affect Q as more and more water is added to interior surfaces of the rock, what physical or chemical characteristics of water are responsible for its effect on Q? We had previously shown (1) that a variety of volatiles could have large effects on the Q of a terrestrial analog of lunar basalt, when the rock was exposed to the volatile at its equilibrium vapor pressure. In the present experiments the Q measurements were done systematically as a function of relative partial pressure (humidity). The volatiles used were benzene, hexane, methanol, ethanol, water and some of their physical properties are listed in Table 1. The volatiles, especially the alcohols, were carefully dried in molecular sieves to remove trace amounts of water. For purposes of elucidating the mechanism and enabling adsorption in measurable amounts, a high porosity sample (orthoquartzite with 9% porosity) was chosen. The results are presented in Fig. 1 and show that volatiles such as benzene and hexane have little effect on Q until relatively high partial pressures are achieved. Water and the alcohols decrease Q significantly when only small amounts are present. Adsorption isotherm data revealed that at low P/P_o the amounts (mg/gm sample) of benzene and hexane adsorbed are roughly half those for water and the alcohols. Simultaneous velocity measurements showed noticeable reductions in velocity with P/P_o of the alcohols and water but negligible changes with benzene and hexane.

These results, when interpreted in the light of previous data (1,2) suggest that (a) there are two mechanisms of attenuation; one which is dependent on the surface interaction of the volatile molecules and grains at low partial pressures and another at very high partial pressures which appears to depend only on condensation of a sufficient amount of volatiles in the pores to obtain fluid flow; (b) benzene and hexane are not as effective in reducing Q at low P/P_o as the alcohols and that water is most effective; (c) among the physical properties, the dipole moment is a key parameter; (d) the polar nature of water and the alcohols may lead to adsorption of greater volatile amounts, stronger bonds to the surface, and access to less favorable sites such as surfaces in fine cracks and crack tips. This picture is re-enforced by independent data (3) showing that adsorption energies of volatiles on quartz are higher for water than for benzene or hexane; (e) the velocity data suggest that the polar volatiles tend to open-up or re-open cracks. The presence of water has long been known to aid in crack growth in silicates (4).

Some of the mechanisms proposed involve relaxation processes which typically involve an internal friction peak. To test for the presence of a relaxation peak at near-seismic frequencies, measurements of the detailed temperature dependence of Q were carried out at 45Hz over a range of temperatures from near-lunar surface values to those corresponding to the interior of the lunar crust. The terrestrial analog of lunar basalt (1) was measured under



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N₂ and H₂O vapor. Prior to each experiment the sample and sample chamber had been moderately outgassed so that some adsorbed water was still present in the sample. Under 5 Torr N₂ the sample exhibited low and reversible Q^{-1} values near 0.8×10^{-3} over most of the temperature range except at about 250°C where a peak of Q^{-1} near 1.3×10^{-3} was observed. Under 5 Torr H₂O the peak was found to broaden so that the Q^{-1} rose to nearly the same level as that of the peak over most of the temperature range. From the frequency and temperature values, a rough estimate for the activation energy at 30 kcal could be calculated. This value is in reasonable agreement with the desorption energy of water adsorbed onto soda lime silicate glass (6). Further measurements are underway to test if the peak moves to lower temperatures with decreasing frequency as required by the standard relaxation process. If the mechanism is confirmed than it might help explain the frequency dependence of Q_s recently deduced from an expanded data set of the lunar seismic data (7).

Techniques for detailed measurements of the frequency dependence of Q have been developed for two reasons: Laboratory measurements are most conveniently made in the kHz and MHz ranges. For data obtained from these experiments to be useful, a method must be available to extrapolate the laboratory data to frequencies used in the field which are generally lower than 100Hz. The frequency dependence of Q is predicted by many models of attenuation processes. Detailed experimental data on frequency dependence are essential in evaluating proposed mechanisms. A critical issue for quantitative comparisons of absolute Q over the entire frequency range is that the measurements be carried out on similar samples. A recent breakthrough in our work now allows measurements on one and the same samples over five decades from the 10Hz range to the 100kHz range. At this time, the measurements are limited to Q_y and V_y (Young's modulus mode of vibration) but plans and preliminary experiments are underway to extend measurements to Q_s and V_s (shear modulus) over the same frequency range. With a knowledge of Q_y , V_y , Q_s and V_s , one may calculate Q_p and V_p (longitudinal waves) from expressions already derived (8). The cylindrical sample is studied in flexure with end-loading in the 10 to 500 Hz range depending on the inertial masses used. Without endloading, the fundamental flexural mode and its harmonics allows measurements on the same sample in the 1 to 15 kHz range. Next vibrating the sample in the extensional mode the measurements are extended from 15 to 90 kHz with the use of harmonics as before. Since many measurements are made in the 0.1 to 2 MHz range, the sample is now cut into 3 cm long sections which are each measured by the pulse transmission method. These methods have all been tested separately and are now ready to be used in one operation.

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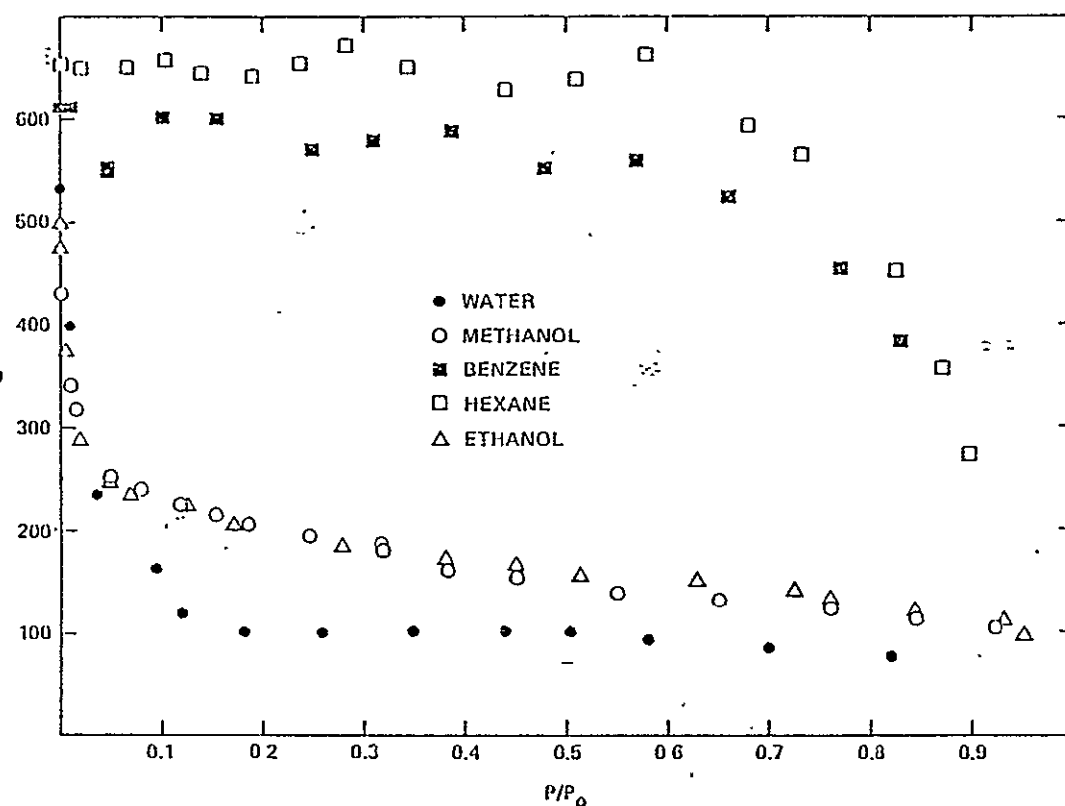


Fig. 1 Q vs. relative partial pressure

TABLE 1

PROPERTIES OF VOLATILES USED IN ADSORPTION EXPERIMENTS

	MW	bp° C	Vapor Pressure (mm)	Viscosity cp (20° C)	Surface tension (liquid-air) dynes/cm	Dipole Moment Debye	A_m^* (calc.) \AA^2	A_m^* (exp.) \AA^2	Density g/cm ³
HEXANE	86.18	68.0	144.3	.33	18.43	0	39.2	51.5	.659
BENZENE	78.11	80.1	90.5	.65	40.04	0	30.5	30-50	.879
METHANOL	32.04	65.0	113.1	.60	22.6	1.7	18.0	--	.791
ETHANOL	46.07	78.5	54.0	1.2	22.75	1.69	23.0	--	.789
WATER	18.0	100.0	22.4	1.0	73.05	1.85	9.6	10.6	1.00

* Molecular Surface Areas